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DEVELOPMENT OF THE HYBRID APPROACH TO DATA PROCESSING

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INTERDISCIPLINARY APPLICATION AND INTERPRETATION OF ERTS DATA WITHIN THE SUSQUEHANNA RIVER BASIN

Resource Inventory, Land Use, and Pollution

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DEVELOPMENT OF THE HYBRID APPROACH TO DATA PROCESSING

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In response to a request by MITRE Corporation[1], ORSER evaluated two approaches to ERTS-1 MSS data analysis: photointerpretation of imagery, and computer processing of digital tapes. Subsequently, ORSER combined these two methods, developing the hybrid approach to ERTS data processing. This method has been successfully applied in many of the research projects conducted by ORSER personnel in the past year. The development of the hybrid approach to data processing is discussed here.

A site consisting of 144 square miles surrounding Harrisburg, Pennsylvania, was chosen for study of land use categories. Initially, two separate research teams studied the two forms of ERTS-1 data, imagery and digital computer tapes. Weeden and Bolling concentrated their efforts on using photointerpretive techniques on ERTS imagery, while Borden and Applegate analyzed the digital data using only USGS 7 1/2 minute quadrangle maps as a reference. As the objective at this preliminary stage was to determine the extent to which these two different approaches might succeed individually in mapping land use, there was no interaction between the two teams during the first few weeks of the study.

Photointerpretation of ERTS-1 Imagery

The imagery used in the photointerpretation study was that of September 6, 1972, covering the Harrisburg area, namely image number 1045-15243 in the four channels of the multispectral scanner (MSS). This ERTS scene was chosen as the best representation of the study area available at the time. The photointerpretation was carried out independent of outside aid. There was no ground truth study of the test

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[1]ORSER performed this work under Mitre Purchase Order N35490, as directed by Edward A. Ward. For the sake of convenience, ORSER used the same test area to work out the combined techniques, although this phase of the project was not under the sponsorship of the Mitre Corporation.

area, no coordination with other researchers using computer programs, and no previous study of maps or aerial photos at larger scales. The intent was to determine what could be read directly from ERTS imagery alone. Although both interpreters had a traveler's acquaintance with the Harrisburg area, care was taken not to identify items by their geographic location. Graytone variations were recorded, but interpreted only where their shape provided interpretive clues.

The imagery was studied under the following conditions:

1. Direct inspection of the image on a light table under magnifications of 4.5X and 7X, using a direct viewing lens or one lens of an Old Delft stereoscope.

2. Projection of the image by means of a Visucom overhead projector, from 10 ft, onto a flat screen at a magnification of 4X.

3. Projection of the image onto a table by means of a single Kelsh Plotter projector, at a magnification of 4.5X.

4. Projection of a glossy positive 4X enlargement using a Saltzman projector, resulting in a further enlarged scale of 7.5X (or 2 miles to the inch).

The above systems were, as far as we know, the only ones available at The Pennsylvania State University at the time. Working at contact scale proved useless for documentation, although considerable detail could be observed with the hand lens. The overhead projector also could not be used, as the projected image could be viewed clearly only from a position of several feet from the screen. The Kelsh Plotter was second only to the Saltzman in usefulness. It permitted direct projection of the image onto a table, where features could be mapped as observed. However, only a very small portion of the image could be viewed at one time, making it difficult to determine significant graytone signatures and to maintain consistency in delineating them. Mapping by this method was, in addition, a very slow process. The Saltzman projector appeared to give the best overall image definition combined with rapid tracing of observed features. It's chief drawback was the necessity of using photographic prints rather than the images themselves, resulting in some loss of graytone resolution.

Positive glossy prints of the portion of the ERTS scene covering the test area were made for use in the Saltzman projector. Only a small portion of the site (approximately 36 square miles) was chosen for study, as this portion was considered to be sufficient to illustrate the problems involved and the results obtainable by photointerpretive techniques. The time involved in producing land use maps from these prints, using the Saltzman, varied from 1 to 2 1/2 hours, depending on the channel. Channel 5 took the longest, and channels 6 and 7 the shortest, time to map. The results were of such quality that it was not considered worthwhile to attempt to planimeter the areas for quantification of the land use categories. Table 1 summarizes these results. It can be seen that in only a few cases could a feature be uniquely determined by this technique, and in virtually no case could it be completely delineated. On no channel was it possible to unambiguously determine areas of suburban development and agriculture. A comparison of results from the four channels reveals widely differing assignments of areas to these two categories, as well as to the category of "forest." In several areas, on all channels, it was not possible to determine accurately the shoreline of the Susquehanna River. Only two orders of streams could be seen: the Susquehanna River and major streams entering it. A few lesser streams were seen on the original imagery by inspection with the hand lens. Subsequent discussion with other researchers indicated that better images are obtainable and somewhat greater detail can be mapped on these.

This study clearly revealed that photointerpretive techniques, when applied to ERTS imagery, are unsatisfactory as a single means of determining land use categories, for the following reasons:

1. It is not possible, by the means attempted here, to unambiguously delineate areas of land use categories or water quality.

2. Establishment of indices for land use categories requires planimetry of areas. Where areas cannot be clearly outlined their size cannot be accurately determined.

3. Up to 2 1/2 hours were spent in mapping a small portion of the study area in a single channel. Clearly, mapping an entire ERTS scene in all four channels would take a large amount of time with very limited useful results.

4. A brief inspection of U2 imagery (flown at 60,000 ft) of the same area indicates that some improvement of photointerpretive

Table 1: Results of Photointerpretation of ERTS Imagery Using the Saltzman Projector

Land Use Category	Channel 4	Channel 5	Channel 6	Channel 7	Preferred Channel
Drainage	Incomplete. Islands obscured. Shorelines grade into forest.	Incomplete. Shorelines grade into forest.	Confused with urban.	Some confusion with urban.	Seven
Roads	Very incomplete.	Clearly defined where white. Unrealiable when parallel to scan lines. Many dark lines could be roads or drainage.	Rarely seen and poorly defined.	Rarely seen.	Five
Urban	Grades into suburban.	Confused with probable bare fields. Otherwise fairly distinct.	Minor confusion with suburban	Confused with drainage.	Five and six
Suburban	Not differentiable from urban. Confused with agriculture.	Not differentiable from agriculture.	Confused with agriculture.	Fair to poor distinction from both agriculture and urban.	All poor, due to confusion with agriculture.
Forest	Not differentiable from drainage and often confused with agriculture.	Some confusion with drainage.	Confused with agriculture.	Confused with agriculture.	Five

(Continued)

Table 1 (Continued)

Land Use Category	Channel 4	Channel 5	Channel 6	Channel 7	Preferred Channel
Agriculture	Confused with forest and often with suburban.	Not differentiable from suburban.	Confused with both forest and suburban.	Confused with forest and with portions of suburban.	All poor, due to confusion with forest and suburban.
Construction	Confused with established concrete areas (e.g., airport) and areas of erosion.	Confused with established areas of concrete and with urban.	Indistinct.	Not visible.	Four.
Erosion and siltation	Confused with construction.	Not visible.	Not visible.	Not visible.	Four.

techniques could be realized by using U2 photography to train the photo-interpreter to recognize ERTS signatures. This would, however, considerably increase the time requirements for a given area of investigation.

5. Better images are now available for the use with the Saltzman technique. These images are produced by photographic enhancement at the expense of radiometric fidelity. However, enhanced images are recommended when photointerpretive techniques are required for a "first look."

Digital Analysis of ERTS-1 Data

The data used in the digital analysis of the study area was from August 1, 1972, scene number 1009-15244. Cloud cover was inconsequential over the area of interest. All four MSS channels were used in data processing; however, channel 7 was of poor quality. Using an Ozalid print of the channel 7 image as a guide, two subsets of the full scene were put on two separate subset tapes, using the SUBSET program[1]. This program, in addition to selecting the subsets, reformats the data to be compatible with all of the analysis and mapping programs of the ORSER data processing system. The first subset was defined as scan lines 937 through 1150 and elements 2790 through 3010. The second subset consisted of lines 1051 through 1200 and elements 3010 through 3228. Both of the subsets came from the third tape of the four for the scene.

The first step in the analysis was the production of a brightness map of the area, using the NMAP program, for the purpose of locating patterns and targets in the area of interest. This initial output (and all subsequent computer map output) was compared with USGS 7 1/2 minute quadrangle maps of the area, printed in 1963 and 1969. A uniformity map was then produced, and five signature training areas were defined on this UMAP output. These areas were: river water, forest, railway yard, central urban, and an unknown target which was found to be similar to the forest target. The training areas were defined for the STATS program and the mean vectors (spectral signatures) and covariance matrices were computed.

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[1]For complete program descriptions, see ORSER-SSEL Technical Report 10-73.

Uniform areas could not be found for many targets. For example, clusters of uniform elements were either nonexistent or too small for reliable signatures for creek water. The cluster analysis program (DCLUS) was modified and used to estimate signatures for creek water, roofs (e.g., tops of large building complexes), and highways. The central urban and railroad signatures obtained with training areas were verified by cluster analysis. The two methods produced results in perfect agreement. The highway signature obtained by cluster analysis was found to be a great deal more general than for highways alone. By using the signature for classification and mapping large areas, it was found that suburban areas were very well mapped with the highway signature and it was therefore renamed.

After an initial set of signatures was obtained, trial maps of blocks of data in the subsets were made. A second stage of target and signature determination was begun on the basis of these maps. The areas which were unclassified were investigated and, by the use of the methods applied before, additional signatures and targets were identified. At this stage, training areas were allowed to include a lower level of uniformity. The number of observations and the number of subareas within the training area for each target were, therefore, substantially increased to overcome the effect of decreased uniformity. The 7 1/2 minute quadrangle maps were used in target identification to make sure that all subareas included in a training area were of the same target.

Having obtained these additional signatures, the whole area from both subsets was mapped. Only 10 to 15 percent of the area remained unclassified. The patterns of unclassified elements appeared to be related to non-urban land use, possibly agriculture. One of these areas by chance fell within the boundaries of the cluster analysis used for the determination of the creek signature. The cluster analysis had classified the area homogeneously and the pattern matched the pattern of the unclassified area on the large map. The signature for OPEN LAND, was taken from that run. Three Mile Island, on the Susquehanna River, is mapped on the 1963 Middletown 7 1/2 minute quadrangle sheet as open land. However, initial processing indicated that the area is now something other than open land, and a check of the underflight photography of the island revealed the construction of an atomic power plant. A cluster analysis was run on the island and surrounding water area, resulting in the signature BUILDING. This signature, in addition to yielding a classification for Three Mile Island, filled in substantial areas in the Harrisburg metropolitan district which had been previously unclassified. From the quadrangle maps these areas appeared to consist of heavy industry and warehouses. The final map was based on a set of thirteen signatures and only three percent of the total area remained unclassified. The full set of category information, with signatures, is given in Table 2.

The euclidean distances of separation of categories are given in Table 3 . A critical distance of 10.0 was used for every class except RIVER WATER, which had a value of 15.0 assigned to it. In the classification scheme, an element was assigned to the class for which the euclidean distance from it to the class signature was smallest if the distance was smaller than the critical distance for the class. If the distance was greater than the critical distance, the classification would be attempted for the next nearest class, and so on. If the element could not be assigned to any class under these rules, it was unclassified. Consider RIVER WATER, for example. The distance of separation from each of the other categories is, in every case, greater than 15.0. Therefore, there is no chance of confusion between RIVER WATER and any other category according to the rules of classification. There are a few other categories for which the same is true, based on the critical value of 10.0. For most of the classes, however, there exist a few distances which indicate potential confusion. Consider classes 2 (RAIL) and 5 (URBAN) of Table 3 . The distance of separation between these two classes is only 2.3. There is, therefore, a potential for confusion between the two classes.

Three other pairs of classes have small distances of separation which should be mentioned. In addition to the aforementioned problem with the RAIL signature, this signature also has a relatively small distance of separation from the CREEK signature. Whether confusion actually exists or not in classifying rail and creek targets can only be resolved by ground truth. It is possible that there might be enough

Table 2: Category Information for the Full Set of Signatures

Number	Name	Symbol	Limit	Ch 4	Ch 5	Ch 6	Ch 7	Count	Percent
1	FOREST 1		10.0	29.28	18.76	46.68	27.60	3655	8
2	RAIL		10.0	37.00	29.45	29.09	10.91	887	2
3	RIVER	W	15.0	33.18	22.48	17.76	4.78	2956	6
4	VEGETATION		10.0	31.78	21.61	41.06	22.00	1249	3
5	URBAN	*	10.0	36.13	28.25	29.71	12.58	1622	3
6	GRASS	-	10.0	32.83	22.83	43.79	22.50	6844	14
7	FOREST 2		10.0	28.25	18.21	49.54	29.82	5329	11
8	ROOF	V	10.0	52.50	55.00	56.00	22.00	130	0
9	SUBURB	#	10.0	38.74	31.88	48.01	23.88	11796	25
10	PAVEMENT	@	10.0	40.59	36.50	51.95	25.59	2738	6
11	CREEK		10.0	33.30	23.52	31.04	13.48	1119	2
12	OPEN LAND		10.0	33.40	22.74	61.00	35.23	5303	11
13	INDUSTRY	+	10.0	42.42	37.58	39.20	15.90	2241	5
	UNCLASSIFIED							1425	3

Table 3: Distances of Separation for Mapping Categories

Categories	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.0	27.6	37.2	8.8	25.5	8.0	3.8	44.4	16.7	21.8	22.0	17.2	26.8
2	27.6	0.0	15.1	18.8	2.3	20.3	31.3	41.7	23.1	28.3	7.7	40.8	14.9
3	37.2	15.1	0.0	29.0	15.7	31.5	41.0	56.5	37.4	43.1	15.9	52.9	29.9
4	8.8	18.8	29.0	0.0	16.7	3.2	12.5	42.0	14.3	20.8	13.4	24.0	20.2
5	25.5	2.3	15.7	16.7	0.0	18.4	29.2	42.0	22.0	27.4	5.7	39.1	15.1
6	8.0	20.3	31.5	3.2	18.4	0.0	11.4	39.6	11.7	18.0	15.6	21.4	19.3
7	3.8	31.3	41.0	12.5	29.2	11.4	0.0	45.2	18.3	22.6	25.7	14.4	29.6
8	44.4	41.7	56.5	42.0	42.0	39.6	45.2	0.0	28.1	22.7	45.3	40.1	26.9
9	16.7	23.1	37.4	14.3	22.0	11.7	18.3	28.1	0.0	6.6	22.3	20.2	13.7
10	21.8	28.3	43.1	20.8	27.4	18.0	22.6	22.7	6.6	0.0	28.4	20.4	16.2
11	22.0	7.7	15.9	13.4	5.7	15.6	25.7	45.3	22.3	28.4	0.0	37.0	18.8
12	17.2	40.8	52.9	24.0	39.1	21.4	14.4	40.1	20.2	20.4	37.0	0.0	33.9
13	26.8	14.9	29.9	20.2	15.1	19.3	29.6	26.9	13.7	16.2	18.8	33.9	0.0

sediment, low vegetation, and water in the yards to give a true response for the creek classification. The two other pairs of categories with small separation distances are CREEK with URBAN, and HIGHWAY with SUBURB. The reason for the similarity of CREEK and URBAN signatures is not known at this time. The similarity of the HIGHWAY and SUBURB signatures was not unexpected, because the initial highway signature was renamed SUBURB when it gave very good mapping results for suburban areas. The new highway signature was obtained later on and may indeed have also been based on targets very similar to those of the suburban signature. It seems, however, that the new highway signature is more related to parking lots and similar paved and unpaved areas than it is to the suburban signature. Actual highways are mapped by both symbols.

Some serious problems exist in naming the categories. Some of them are easily named correctly, such as RIVER WATER and FOREST. Little emphasis was put on the names of other categories because they were named only inferentially, with no direct means of being sure of the targets. It is not at all an easy matter to pick out vegetation signatures in ERTS data simply by looking at the signatures. It is even more difficult to identify other signatures. The quadrangle maps are of limited utility since they do not generally give the kind of information needed to identify a category except on an inferential basis. Ground truth or aerial photographs, such as used in identifying the construction on Three Mile Island, would have been very helpful in specifically identifying and naming the targets.

A small part of the DCLASS map is shown in Figure 1 . The river and islands in the river are readily apparent. The central metropolitan area of Harrisburg, mapped with *'s, can be seen in the upper right portion of the figure. Heavy industrial and warehouse areas, mapped with +'s, can be seen adjoining the downtown area of Harrisburg. Across the river, the Camp Hill suburban area can be seen mapped with #'s. The @'s in Camp Hill possibly indicate parking lots or bare ground, and the -'s indicate parks, cemeteries, and similar green areas. A summary of the mapping results is included in Table 2 . The percentage in each category is the relative acreage in the category. The count for each category is the actual number of elements classified in the category.

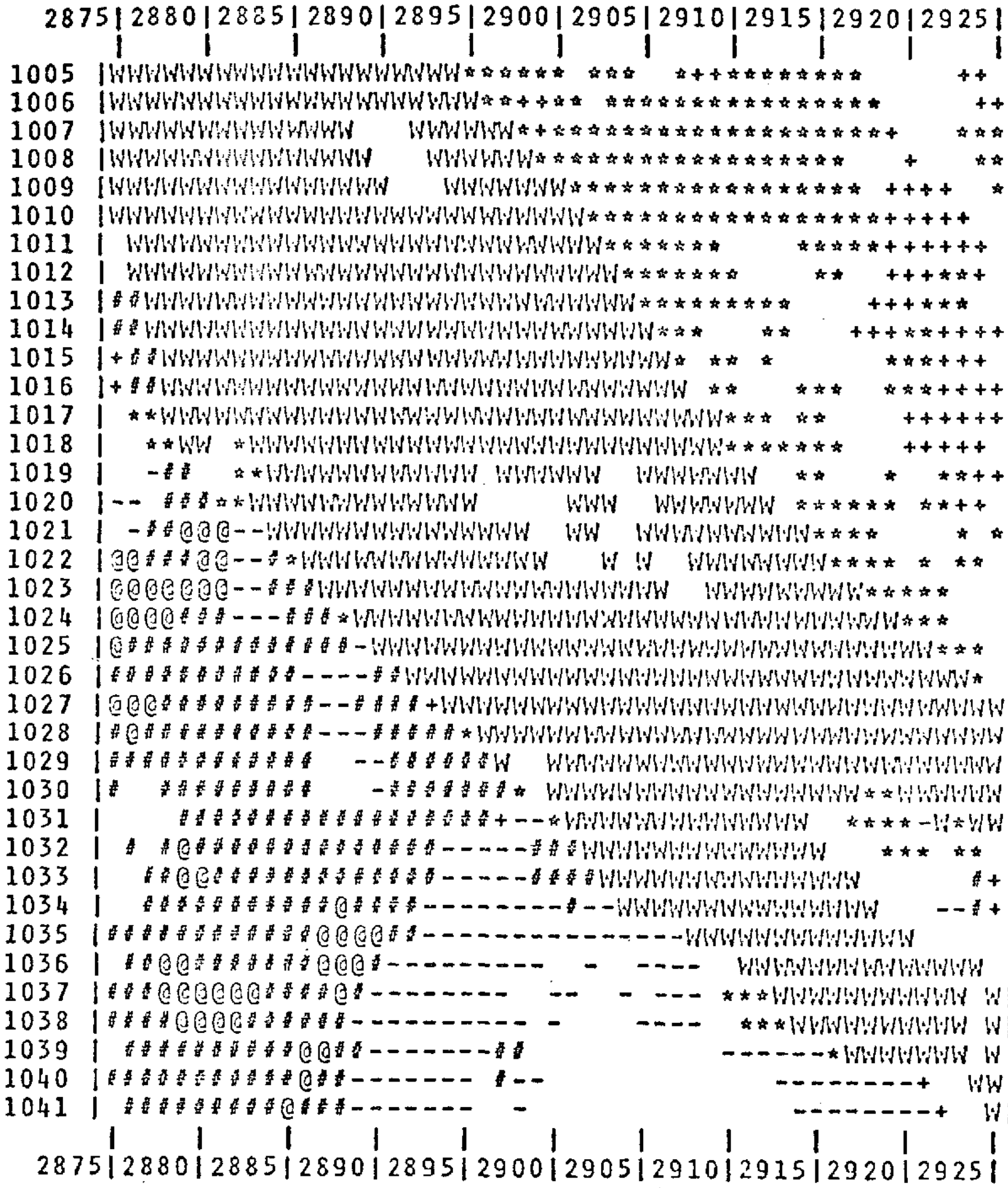

Figure 1: Portion of DCLASS map of the Harrisburg area, with six categories. Symbols are defined in Table 2 and described in the text.

The conversion factor to acreage is approximately 1.12 acres/element, based on the distance of separation between elements in a line and between lines.

The results of this study amply demonstrate that ERTS-1 data can be translated to maps using only USGS 7 1/2 minute quadrangle maps for reference. The computer generated maps agree quite well with the quadrangle maps except that the fine detail of the latter maps cannot be achieved with ERTS-1 data. The ERTS data based maps indicate that more significant land use categories can be mapped than has been done on the quadrangle maps. In addition, the obvious and serious deficiency of the quadrangle maps is very strongly demonstrated: they are obsolete in many areas, even over the short period of time since the 1969 publication dates. The maps made in 1963 are of exceedingly limited utility in areas where rapid transitions in land use are in evidence. Because of their obsolescence and the absence of sufficient land use classification categories, the use of USGS quadrangle maps alone to support ERTS data based mapping is definitely inadvisable. Underflight photography or imagery, and photointerpretation of these, are, without question, a needed basis of support for digital mapping of ERTS data. Some timely ground truth is also necessary to resolve anomalies. It was found that very little else could be done without such additional support. Signatures could be refined and the number of signatures could be increased, but there was no justification for such additional work since the end result would be the same, in that the interpretation would still lack sufficient support.

Combined Techniques

After separate analysis of ERTS-1 data by photointerpretation alone and by computer processing of MSS digital data without the assistance of photointerpretation, it became apparent that each method had shortcomings which might be overcome if the methods were combined. Computer differentiation of areas from scanner data is far superior to that done by the human eye. Computation of areas from the digital data makes delineation of these areas unnecessary and is far more accurate than planemetric methods at the scale of ERTS MSS imagery. Since the end result of processing ERTS-1 data is a map, the automated processes of thematic mapping by computer is the efficient way to go. However, "ground truth" is the key to correct signatures for this mapping. Underflight data and photointerpretation of underflight photography, as well as of ERTS imagery, are vital links leading to valid signatures for the thematic map. A marriage of these two disciplines, photointerpretation and computer processing, is essential for maximum utilization of ERTS-1 data. The two analysis teams, therefore, combined forces and evolved a method of ERTS MSS data analysis referred to as the "hybrid approach" and shown in Figure 2 . This method involves intimate interaction of the computer analyst and the photointerpreter, using high-altitude photography (U2) for comparison with the computer output. The hybrid approach was first successfully applied in a land use study of the Harrisburg area originally examined by the two separate methods. This study is discussed in ORSER-SSEL Technical Report 14-73.

Conclusions

ORSER feels strongly that a hybrid approach is essential to ERTS data analysis. Computer differentiation of areas from scanner data is far superior to that done by the human eye; but the photointerpreter, working with underflight photography, is an essential and integral part of data processing for providing identification of features exhibited on computer output.

The results of this investigation has shown that ERTS digital data can be translated into map form using only USGS maps for reference. However, such maps are frequently insufficient to provide enough information for classification, particularly in areas where rapid transitions in land use are evident and maps become obsolete very quickly. It has also been shown that photointerpretation techniques can be applied to ERTS imagery. However, in only a few cases could a feature be uniquely determined by this method alone. The use of U2 and C130 imagery has been found to improve these interpretation results, but photointerpretive techniques have not been completely satisfactory as a single means of analysis.

Explanation of the steps shown in Figure 2.

PRELIMINARY PROCEDURES

A.[1] Determine scan line and element limits.
B. This becomes the working tape.
C. Identify clouds.
D. Review scene for definable boundaries.

FIRST LEVEL MAPPING

A. Collaboration of the photointerpreter and computer mapper. Select easiest targets first. Choose spectrally homogeneous items with positive geographic locations. Select replications in widely separated areas.
B. Identify some targets (training areas) on NMAP or UMAP.
C. Check for uniformity on UMAP. Attempt to find a large number of like elements. Loop A, B, and C until a sufficient number of training areas are identified.
D. Review statistical characteristics of defined targets.
E. Make first run on classification map.
F. This is a verification step. Project U2 image onto computer map. Identify satisfactory classifications. If some areas lack definition, redefine training areas.

SECOND LEVEL MAPPING

A. Attempt to identify items outside training areas.
B. Define items not subject to definition by training areas. These might be linear features or stream channels. Add these to the list of signatures and continue.
C. This a recycle, with smaller training areas and more weight placed on cluster analysis.

THIRD LEVEL MAPPING

A. Review the classification categories originally defined as desirable. If present map output is unnecessarily refined, combine some groups.
B. Some categories will require broadened spectral parameters. A series of successive approximations will be required to define these units. The resulting training areas will be less spectrally homogeneous.
C. Requires collaboration of the photointerpreter and the computer mapper.
D. Establish limiting goal.

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[1]The letters correspond directly to those shown in the diagram.

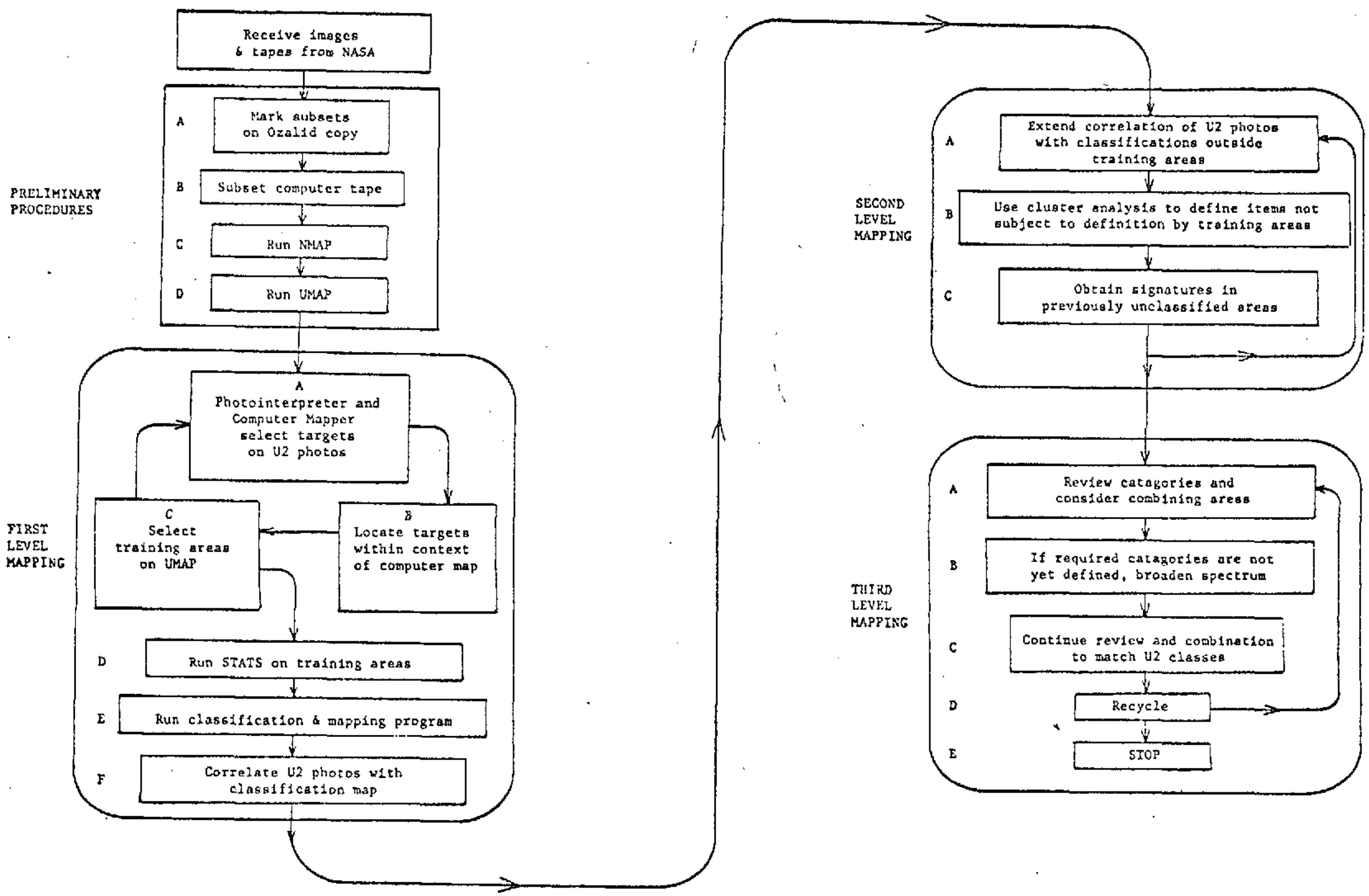

Figure 2 : Flow diagram for the hybrid approach to ERTS data processing.